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A NOTE ON ENVIRONMENTAL
INNOVATION

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A Note on Environmental Innovation*

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Abstract

The purpose of this exploratory note is, first, to alert the reader to the negative impact of allowance markets on environmental innovations and, second, to suggest some improvements. Stand-alone spot markets enable the government to expropriate an innovation by offering a competing "technology" (pollution permits) and putting an arbitrary downward pressure on the licensing price. Advance allowances reduce expropriation but still create very suboptimal incentives for innovations. They have the further drawback that permits are inefficiently used when the innovation occurs. In this respect, options to pollute at a given striking price fare better than allowances because they create private incentives to phase out pollution in case of innovation.

The note then studies government procurement. Surprisingly ex-post licensing by the innovator to the government may yield a higher licensing fee than an ex-ante contract.

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1 Introduction

In a companion paper (1994) we analyze the impact of spot and futures markets for tradeable pollution permits on the potential polluters' compliance decisions. The focus there is on the individual incentives to *adopt* pollution abatement devices. In contrast, this exploratory note considers technological *innovation*, namely the invention of substitutes or pollution abatement devices that can be used by all polluters. The innovation is therefore a *public* good, while the investments considered in the companion paper are purely *private*.

2 The model

There are two dates, $t = 1, 2$, and a continuum of agents/potential polluters. For notational simplicity, we assume no discounting. Without loss of generality, we also do not consider first-period pollution. The agents' demand curve for second-period pollution rights is given by $n = N(p)$, where p is the (second-period) spot price. The function $N(\cdot)$ is decreasing. Unlike in our companion paper, we do not allow agents to make individual investments in pollution abatement (although this could be incorporated into the analysis). So, the demand function is fixed.

Let $D(n)$ denote the social damage of pollution, where $D' > 0$, $D'' > 0$. The government faces a shadow cost of public funds $\lambda > 0$; that is, raising \$1 of public money costs society \$$(1 + \lambda)$ because of distortionary taxation.

We model innovation in a simple way. There is one potential innovator, who at private cost $C(x)$ incurred at date 1 ($C(0) = 0$, $C'(0) = 0$, $C'(1) = +\infty, C' > 0$, and $C'' > 0$ for $x > 0$) innovates with probability x at the beginning of date 2. The innovation is a pollution-free perfect substitute for the existing polluting good, or else is a pollution abatement device that can be installed at no cost on any existing equipment and eliminates all pollution (we will use this second interpretation.) We will consider two cases depending on whether a contract can be signed with the potential innovator before she performs R & D. If such an *ex ante* contract can be signed (as in section 5), we will assume that the innovator is protected by limited liability (or, equivalently, is very risk averse under income zero). It will become clear that we could consider more sophisticated descriptions of the R & D process. When no ex ante contract is signed (sections 3, 4 and 6), the innovator is simply granted a patent on her innovation.

3 Spot market

This section assumes that the government issues pollution permits in period 2 after observing whether the innovation occurs. The second-period timing is as follows: (i) the innovator invents or not; (ii) the government sets a price p for pollution permits[2]; and (iii) the innovator sets a price ℓ on licenses.

Let us first analyze the pricing game. In the absence of innovation, the regulator chooses price p so as to solve:

$$\max_p \{ \int_p^\infty N(x)dx + (1+\lambda)pN(p) - D(N(p)) \}.$$

Letting $\eta(p) \equiv -\frac{dN/dp}{N/p}$ denote the elasticity of demand for pollution permits, we obtain the standard Ramsey formula:

$$\frac{p - \frac{D'(N(p))}{1+\lambda}}{p} = \frac{\lambda}{1+\lambda} \frac{1}{\eta(p)}, \tag{1}$$

where $D'/(1+\lambda)$, the marginal damage expressed in monetary units, is the marginal cost of "producing the 'good pollution'".

In case of innovation, the inventor, who has a lower cost (namely 0) of enabling agents to produce than the regulator (who has marginal cost $D'/(1+\lambda)$), always undercuts slightly the price for pollution permits. Welfare is therefore equal to $\int_p^\infty N(x)dx$.[3] The regulator therefore chooses:

$$p = 0. \tag{2}$$

Because the innovator does not make a profit in either state of nature, she rationally chooses not to perform R&D ($x = 0$).

4 Advance allowances

This section shows that, while spot markets destroy incentives for innovation (see section 3), futures markets bring limited improvement, even if the regulator can commit not to issue permits in order to exert downward pressure on the license fee. Granting advance rights to pollute both substantially discourages innovation and may induce a suboptimal adoption. In case of innovation, ***the spot price adjusts downward so as to allow permits to compete with the innovation.*** By exerting price pressure on the licenses of the innovation,

[2]We could alternatively allow the government to choose the *number* of permits instead of their price. The treatment of this case would follow the lines of the analysis in section 4.

[3]This expression holds as long as the price does not exceed the inventor's monopoly price. But it is clearly inefficient to set a price above the monopoly price.

allowances substantially devalue the innovator's property right and reduce the incentive to innovate.

To illustrate this simple point, consider the following extreme example: There are $\overline{n}$ potential polluters and $\overline{n}$ advance permits sold in period 1. In case of innovation, the spot price falls to zero and so does the price of licenses sold to the $\overline{n}$ polluters. The innovator rationally chooses not to perform R & D ($x = 0$), even though the innovation eliminates the $\overline{n}$ units of pollution and is awarded a patent.

Advance permits have a second perverse effect, that need not occur in this extreme example, but does occur more generally. Let us first assume that the innovator is not allowed to trade on the permits market. Unless the equilibrium price for pollution control (through either a license from the innovator or a permit) is equal to zero (in which case the innovation does not take place anyway), the existing $\overline{n}$ permits are used *ex post* even though the innovation could completely eradicate pollution. Let $N(p)$ denote the second-period demand curve, with inverse demand $P(n)$. And consider the following timing after the innovation occurs: a) the innovator sets a license price p, (b) then the market for permits clears. Either $p \geq P(\overline{n})$ and no license is sold (which is not optimal for the innovator); or $p < P(\overline{n})$ and the innovator *de facto* picks the price on the spot market for permits. The number of licenses sold is then $[N(p) - \overline{n}]$. So, *the level of pollution is the same as in the absence of innovation.* The only positive effect of innovation is that it allows more potential polluters to produce.

Let us now analyze the innovator's choice of pricing and R & D intensity. Let p^m denote the constrained monopoly price for the innovator:

$$p^m \quad \text{maximizes} \quad \{p[N(p) - \overline{n}]\}. \tag{3}$$

[p^m is actually a slight misnomer. The permits play the role of a competitive fringe, and, by a standard revealed preference argument, force the innovator to charge a lower license price p^m that she would charge in their absence.] Let Π^m denote the resulting maximand. The innovator chooses R & D level x so as to solve:

$$x \quad \text{maximizes} \quad \{x\Pi^m - C(x)\}. \tag{4}$$

To summarize, the sale of advance permits has two perverse effects here: First, the permits partially prevent the adoption of a superior, pollution-free technology. Second, they further reduce the innovator's incentive to innovate (this incentive is already suboptimal in the absence of permits because the innovator does not internalize the increase in "consumer surplus" brought about by the innovation.)

Let us now allow the innovator to trade on the permits market. In the absence of licensing costs, the innovator's profit is independent of the number of permits she

purchases. When purchasing $n \leq \bar{n}$ permits, she faces residual demand curve $N(p) - (\bar{n} - n)$, pays np and has profit $p[N(p) - \bar{n}]$. The innovator's incentives are unchanged and are still quite low. But, if $n = \bar{n}$, the $\bar{n}$ units of pollution are eradicated, and welfare is higher than when the innovator does not trade in the permits market.

Unfortunately, the innovator's (weak) willingness to buy permits on the market in case of innovation disappears when she faces an arbitrarily small marginal cost ϵ of licensing. The innovator's profit, $(p - \epsilon)[N(p) - (\bar{n} - n)] - pn$, is now a strictly decreasing function of the number of repurchased permits n. Allowing the innovator to trade on the market has then no effect.

The crux of the matter is that none of the market participants (polluters, innovator) internalizes the social cost of pollution of the leftover permits. To induce market participants to phase out the wasteful permits in case of innovation, one possibility is to replace these permits to pollute by options with a striking price η exceeding the marginal licensing cost ϵ of the innovator. *In contrast with final sales of permits, sales of options have the desirable property that they provide incentives to make full use of the innovation and therefore to retire previous rights to pollute.* They furthermore have a beneficial impact on the incentive to innovate as they restore some of the innovator's monopoly power lost with the issuance of permits.

Alternatively the government, which internalizes the social cost of pollution of the leftover permits, could respond to innovation by buying back some permits. The government could also purchase the innovation from the innovator (see section 6).

5 Procurement

By opposition with the market-oriented approach of the previous section, this section considers the ideal planning solution. We make the strong assumption that the government can *ex ante* identify the potential innovation and designs an incentive contract for the innovator so as to maximize social welfare.

The government optimally issues no advance permits at date 1. Rather it promises to purchase the innovation at some price q. Once the government acquires the (exclusive) property rights on the innovation, it sells the license at the Ramsey price for the pollution-free technology, namely the price that solves:

$$\eta \equiv \frac{-\frac{dN}{dp}}{\frac{N}{p}} = \frac{\lambda}{1+\lambda}. \tag{5}$$

Let $\hat{W}^R$ denote the associated social welfare. Similarly let W^R denote social welfare when there is no innovation and the government sells the corresponding optimal number of

permits in period 2.[4] The innovator reacts to incentive q by choosing x so as to maximize $\{xq - C(x)\}$ or

$$C'(x) = q. \tag{6}$$

The optimal procurement policy consists in choosing q, or equivalently x, so as to maximize:

$$x\hat{W}^R + (1-x)W^R - (1+\lambda)xq + [xq - C(x)] = x\hat{W}^R + (1-x)W^R - C(x) - \lambda x C'(x).$$

We obtain:

$$\hat{W}^R - W^R = (1+\lambda)C'(x^*) + \lambda x^* C''(x^*). \tag{7}$$

For instance, in the case of a quadratic cost function ($C'(x) = xC''(x)$), one has

$$q^* = \frac{\hat{W}^R - W^R}{1+2\lambda}.$$

Because it is costly to leave rents to the innovator, the prize $q^* = C'(x^*)$ is lower than the social value of the innovation computed at the shadow cost of public funds $\left(\frac{\hat{W}^R - W^R}{1+\lambda}\right)$.

6 Ex post licensing to the government

Suppose now that no contract between the potential innovator and the government can be signed at date 1, but that the government can purchase the innovation at date 2 and, as in the previous subsection, license it to the agents. We assume frequent-offer, alternating-move bargaining between the government and the innovator starting at the beginning of date 2. The government issues short-term pollution permits as long as it has not yet agreed with the innovator (so, we are now treating "period 2" as an infinite-horizon game following period 1). The reader will check that the licensing fee is equal to the one given by the Nash bargaining solution with reservation value W^R for the government (as in Binmore-Rubinstein-Wolinski (1986)):[5]

$$q = \frac{\hat{W}^R - W^R}{2\lambda}. \tag{8}$$

[4] $\hat{W}^R$ and W^R are equal to the maximal values of $\{-\tilde{D}(N(p)) + (1+\lambda)pN(p) + \int_p^\infty N(x)dx\}$ for $\tilde{D}(\cdot) \equiv 0$ and $\tilde{D}(\cdot) \equiv D(\cdot)$, respectively.

[5] Let β denote the discount factor corresponding to the bargaining periods, $\hat{w}^R \equiv (1-\beta)\hat{W}^R$ and $w^R \equiv (1-\beta)W^R$ denote the per-period welfares, and q_g and q_i denote the equilibrium offers when the government and the innovator make the offer. Then:

$$\begin{aligned} q_g &= \beta q_i, \text{ and} \\ \hat{w}^R - \lambda q_i &= w^R - \beta\lambda q_g. \end{aligned}$$

Note that (as is for instance the case for quadratic cost functions) q may exceed q^*. This may seem surprising in view of the asset specificity literature, which emphasizes the role of long-term contracts in reducing expropriation by the buyer and encouraging investment by the supplier through the promise of a high transfer price. There are two differences with the asset specificity literature. First, the buyer (the government) here partly internalizes the seller's welfare. Second, and more importantly, the seller faces limited liability. The utilities are then not quite transferrable, and a long-term procurement contract does not maximize total surplus of the two parties. The licensing fee is reduced so as to limit the innovator's rent.[6] The possibility that *ex post* bargaining yield a higher licensing price than (*ex ante*) procurement is nicely illustrated by the case of a very low shadow cost of public funds. The government is then willing *ex post* to accept almost an infinite licensing price in order not to delay the adoption of the innovation. But it would never agree *ex ante* to such a price because this would give excessive incentives for R & D.

The case in which $q > q^*$ actually raises several issues. First, it is not in the interest of the innovator to sign *ex ante* a contract with the government. Second, as in Hart-Moore (1992), an innovator who has signed an *ex ante* contract might blackmail the government to force it to raise the price from q^* to q to complete the research, if she is indispensable for its completion.

Last, we have assumed that the innovator does not sell short-term licenses to the agents while bargaining with the government. The possibility of short-term licenses makes both parties more patient in the bargaining process. We have not yet studied the net effect.

7 Summary

The purpose of this exploratory note has been, first, to alert the reader to the negative impact of allowance markets on environmental innovations and, second, to suggest some improvements. Stand-alone spot markets enable the government to expropriate an innovation by offering a competing "technology" (pollution permits) and putting an arbitrary downward pressure on the licensing price. Advance allowances reduce expropriation but still create very suboptimal incentives for innovation. They have the further drawback that permits are inefficiently used when the innovation occurs. In this respect, options to pollute at a given striking price fare better than allowances because they create private incentives to phase out pollution in case of innovation.

The note then studied government procurement. Surprisingly ex post licensing by the innovator to the government may yield a higher licensing fee than an ex ante contract.

[6] In a private context, the licensing fee is higher (lower) under a long-term contract if the marginal cost C' is concave (convex).

The limited scope of this note has left many issues unexplored. For example, the role of a futures market as a guide for the agents' individual investments in pollution-abating technologies and the issues of agent rent extraction (that are the focus of our companion paper) were left here out of the analysis. Another desirable extension would describe in more detail the microstructure of the innovation process (see Aghion-Tirole (1993)) and examine how financing, control rights on the process, property rights on the innovation and return from licensing would be optimally split among the several actors (innovator, government, users of the innovation and financiers.) Last, it would be very useful to consider more complex incentive mechanisms than the simple ones (stand-alone markets, futures markets, procurement, and ex post licensing to the government) analyzed here.

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